

Document made available under the Patent Cooperation Treaty (PCT)

International application number: PCT/US05/003988

International filing date: 04 February 2005 (04.02.2005)

Document type: Certified copy of priority document

Document details: Country/Office: US
Number: 60/557,235
Filing date: 29 March 2004 (29.03.2004)

Date of receipt at the International Bureau: 02 September 2005 (02.09.2005)

Remark: Priority document submitted or transmitted to the International Bureau in compliance with Rule 17.1(a) or (b)



World Intellectual Property Organization (WIPO) - Geneva, Switzerland
Organisation Mondiale de la Propriété Intellectuelle (OMPI) - Genève, Suisse

146129



THE UNITED STATES OF AMERICA

TO ALL TO WHOM THESE PRESENTS SHALL COME:

UNITED STATES DEPARTMENT OF COMMERCE

United States Patent and Trademark Office

August 25, 2005

THIS IS TO CERTIFY THAT ANNEXED HERETO IS A TRUE COPY FROM THE RECORDS OF THE UNITED STATES PATENT AND TRADEMARK OFFICE OF THOSE PAPERS OF THE BELOW IDENTIFIED PATENT APPLICATION THAT MET THE REQUIREMENTS TO BE GRANTED A FILING DATE.

APPLICATION NUMBER: 60/557,235

FILING DATE: *March 29, 2004*

RELATED PCT APPLICATION NUMBER: *PCT/US05/03988*



Certified by

Under Secretary of Commerce
for Intellectual Property
and Director of the United States
Patent and Trademark Office

032904

17157 U.S. PTO

Approved for use through 07/31/2006, OMB 0691-0032
 U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No. **EV 417438953 US**

22154 U.S. PTO
 60/557235

032904

INVENTOR(S)				
Given Name (first and middle [if any])		Family Name or Surname		Residence (City and either State or Foreign Country)
DANIEL B. JAMES D.		LAUBACHER MCCAMBRIDGE		WILMINGTON, DELAWARE SWARTHMORE, PENNSYLVANIA
Additional inventors are being named on the _____ separately numbered sheets attached hereto				
TITLE OF THE INVENTION (500 characters max)				
THE USE OF TWO OR MORE SENSORS IN A NUCLEAR QUADRUPOLE RESONANCE DETECTION SYSTEM TO IMPROVE SIGNAL-TO-NOISE RATIO				
Direct all correspondence to: CORRESPONDENCE ADDRESS				
<input checked="" type="checkbox"/> Customer Number:		23906		
OR				
<input type="checkbox"/> Firm or Individual Name				
Address				
Address				
City		State	Zip	
Country		Telephone	Fax	
ENCLOSED APPLICATION PARTS (check all that apply)				
<input checked="" type="checkbox"/> Specification Number of Pages		16		
<input checked="" type="checkbox"/> Drawing(s) Number of Sheets		2		
<input type="checkbox"/> Application Date Sheet. See 37 CFR 1.76				
<input type="checkbox"/> CD(s), Number				
<input type="checkbox"/> Other (specify)				
METHOD OF PAYMENT OF FILING FEES FOR THIS PROVISIONAL APPLICATION FOR PATENT				
<input type="checkbox"/> Applicant claims small entity status. See 37 CFR 1.27.		FILING FEE Amount (\$)		
<input type="checkbox"/> A check or money order is enclosed to cover the filing fees.		<div style="border: 1px solid black; padding: 10px; width: fit-content; margin: auto;"> \$160.00 </div>		
<input checked="" type="checkbox"/> The Director is hereby authorized to charge filing fees or credit any overpayment to Deposit Account Number:				
04-1928				
<input type="checkbox"/> Payment by credit card. Form PTO-2038 is attached.				
The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.				
<input type="checkbox"/> No.				
<input type="checkbox"/> Yes, the name of the U.S. Government agency and the Government contract number are: _____				

[Page 1 of 2]

Respectfully submitted,

Date March 29, 2004

SIGNATURE

REGISTRATION NO. 32,255

TYPED OR PRINTED NAME JOHN A LANGWORTHY

(if appropriate)
Docket Number: CL2466USPRV1

TELEPHONE (302) 992-4362

USE ONLY FOR FILING A PROVISIONAL APPLICATION FOR PATENT

This collection of information is required by 37 CFR 1.51. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 8 hours to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Mail Stop Provisional Application, Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

PROVISIONAL APPLICATION COVER SHEET
Additional Page

PTO/SB/16 (08-03)

Approved for use through 07/31/2006. OMB 0651-0032

U.S. Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

Docket Number CL2466USPRV1

INVENTOR(S)/APPLICANT(S)		
Given Name (first and middle (if any))	Family or Surname	Residence (City and either State or Foreign Country)
CHARLES	WILKER	WILMINGTON, DELAWARE

[Page 2 of 2]

Number _____ of _____

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

FEE TRANSMITTAL
for FY 2004

Effective 10/01/2003. Patent fees are subject to annual revision.

☐ Applicant claims small entity status. See 37 CFR 1.27TOTAL AMOUNT OF PAYMENT (\$)**160.00****Complete if Known**

Application Number	TO BE ASSIGNED
Filing Date	March 29, 2004
First Named Inventor	Daniel B. Laubacher
Examiner Name	
Art Unit	
Attorney Docket No.	CL2466USPRV1

METHOD OF PAYMENT (check all that apply)
☐ Check ☐ Credit card ☐ Money Order ☐ Other ☐ None
☒ Deposit Account

Deposit Account Number	04-1928
Deposit Account Name	E. I. du Pont de Nemours and Company

The Director is authorized to: (check all that apply)

☒ Charge fee(s) indicated below ☒ Credit any overpayments☒ Charge any additional fee(s) or any underpayment of fee(s)☐ Charge fee(s) indicated below, except for the filing fee to the above-identified deposit account.**FEE CALCULATION****1. BASIC FILING FEE**

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description	Fee Paid
1001 770	2001 385	Utility filing fee	
1002 340	2002 170	Design filing fee	
1003 530	2003 265	Plant filing fee	
1004 770	2004 385	Reissue filing fee	
1005 160	2005 80	Provisional filing fee	160.00
SUBTOTAL (1) (\$)			160.00

2. EXTRA CLAIM FEES FOR UTILITY AND REISSUE

Total Claims	Extra Claims	Fee from below	Fee Paid
Independent	-20** =	X 18	
Multiple Dependent	-3** =	X 86	
	YES	290.00	

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description
1202 18	2202 9	Claims in excess of 20
1201 86	2201 43	Independent claims in excess of 3
1203 290	2203 145	Multiple dependent claim, if not paid
1204 86	2204 43	** Reissue independent claims over original patent
1205 18	2205 9	** Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) (\$)**0.00**

**or number previously paid, if greater; For Reissues, see above

FEE CALCULATION (continued)**3. ADDITIONAL FEES****Large Entity, Small Entity**

Large Entity Fee Code (\$)	Small Entity Fee Code (\$)	Fee Description	Fee Paid
1051 130	2051 65	Surcharge - late filing fee or oath	
1052 50	2052 25	Surcharge - late provisional filing fee or cover sheet	
1053 130	1053 130	Non-English specification	
1812 2,520	1812 2,520	For filing a request for ex parte reexamination	
1804 920*	1804 920*	Requesting publication of SIR prior to Examiner action	
1805 1,840*	1805 1,840*	Requesting publication of SIR after Examiner action	
1251 110	2251 55	Extension for reply within first month	
1252 420	2252 210	Extension for reply within second month	
1253 950	2253 475	Extension for reply within third month	
1254 1,480	2254 740	Extension for reply within fourth month	
1255 2,010	2255 1,005	Extension for reply within fifth month	
1401 330	2401 165	Notice of Appeal	
1402 330	2402 165	Filing a brief in support of an appeal	
1403 290	2403 145	Request for oral hearing	
1451 1,510	1451 1,510	Petition to institute a public use proceeding	
1452 110	2452 55	Petition to revive - unavoidable	
1453 1,330	2453 665	Petition to revive - unintentional	
1501 1,330	2501 665	Utility issue fee (or reissue)	
1502 480	2502 240	Design issue fee	
1503 640	2503 320	Plant issue fee	
1460 130	1460 130	Petitions to the Commissioner	
1807 50	1807 50	Processing fee under 37 CFR 1.17(q)	
1806 180	1806 180	Submission of Information Disclosure Stmt	
8021 40	8021 40	Recording each patent assignment per property (times number of properties)	
1809 770	2809 385	Filing a submission after final rejection (37 CFR 1.129(a))	
1810 770	2810 385	For each additional invention to be examined (37 CFR 1.129(b))	
1801 770	2801 385	Request for Continued Examination (RCE)	
1802 900	1802 900	Request for expedited examination of a design application	

Other fee (specify)

*Reduced by Basic Filing Fee Paid

SUBTOTAL (3) (\$)**0.00****SUBMITTED BY**Name (Print/Type) **JOHN A. LANGWORTHY**

Registration No.

32,255

(Complete if applicable)

Telephone (302)9924362

Signature

Date

March 29, 2004

WARNING: Information on this form may become public. Credit card information should not be included on this form. Provide credit card information and authorization on PTO-2038.

This collection of information is required by 37 CFR 1.17 and 1.27. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

TITLE

THE USE OF TWO OR MORE SENSORS IN A NUCLEAR QUADRUPOLE
RESONANCE DETECTION SYSTEM TO IMPROVE SIGNAL-TO-NOISE
RATIO

5

FIELD OF THE INVENTION

This invention relates to a nuclear quadrupole
resonance detection system and the use of two or more
sensors tuned to the same nuclear quadrupole resonance
10 frequency and simultaneously detecting the nuclear
quadrupole resonance signal, thereby providing improved
nuclear quadrupole resonance detection system
performance.

BACKGROUND OF THE INVENTION

15 The use of nuclear quadrupole resonance (NQR) as a
means of detecting explosives and other contraband has
been recognized for some time, see e.g., T. Hirshfield
et al., J. Molec. Struct. 58, 63 (1980), A. N. Garroway
et al., Proc. SPIE 2092, 318 (1993), and A. N. Garroway
20 et al., IEEE Trans. On Geoscience and Remote Sensing
39, 1108 (2001). NQR provides some distinct advantages
over other detection methods. NQR requires no external
magnet such as required by nuclear magnetic resonance.
NQR is sensitive to the compounds of interest, i.e.,
25 there is a specificity of the NQR frequencies.
One technique for measuring NQR in a sample is to place
the sample within a solenoid coil that surrounds the
sample. The coil provides a radio frequency (RF)
magnetic field that excites the quadrupole nuclei in
30 the sample and results in their producing their
characteristic resonance signals. This is the typical
apparatus configuration that might be used for scanning
mail, baggage or luggage. There is also need for a NQR
detector that permits detection of NQR signals from a
35 source outside the detector, e.g., a wand detector,
that could be passed over persons or containers as is
done with existing metal detectors. Problems
associated with such detectors using conventional

systems are the decrease in detectability with distance from the detector coil and the associated equipment needed to operate the system.

A detection system can have one or more coils that both transmit and receive or it can have separate coils that only transmit and only receive. A transmit or transmit and receive coil of an NQR detection system provides a magnetic field that excites the quadrupole nuclei in the sample and results in their producing their characteristic resonance signals that the coil receives. The NQR signals have low intensity and short duration. The transmit, receive, or transmit and receive coil preferably has a high quality factor (Q). The transmit, receive, or transmit and receive coil has typically been a copper coil and therefore has a Q of about 10^2 . It can be advantageous to use a transmit, receive, or transmit and receive coil made of a high temperature superconductor (HTS) rather than copper since the HTS self-resonant coil has a Q of the order of 10^3 - 10^6 . The large Q of the HTS self-resonant coil produces large magnetic field strengths during the RF transmit pulse and does so at lower RF power levels. This dramatically reduces the amount of transmitted power required to produce NQR signals for detection and thereby reduces the size of the RF power supply sufficiently so that it can be run on portable batteries. The large Q of the HTS self-resonant coil also plays an important role during the receive time. In view of the low intensity NQR signal, it is important to have a signal-to-noise ratio (S/N) as large as possible. The signal-to-noise ratio is proportional to the square root of Q so that the use of the HTS self-resonant coil results in an increase in S/N by a factor of 10-100 over that of the copper system. These advantages during both the transmit and the receive times enable a detector configuration that is small and portable. In particular, the use of a high temperature superconductor sensor, i.e., receive

coil, provides a distinct advantage over the use of an ordinary conductor coil.

An object of the present invention is to provide a NQR detection system with improved performance.

5 SUMMARY OF THE INVENTION

This invention provides a method for improving the performance of a nuclear quadrupole resonance detection system comprising:

- 10 a) using two or more sensors tuned to a specified nuclear quadrupole resonance frequency, wherein the two or more sensors simultaneously receive the specified nuclear quadrupole resonance signal; and
- 15 b) adding coherently the signals detected by the two or more sensors to thereby improve the signal-to-noise ratio.

The invention also provides a nuclear quadrupole resonance detection system comprising:

- 20 a) two or more sensors tuned to a specified nuclear quadrupole resonance frequency, wherein the two or more sensors simultaneously receive the specified nuclear quadrupole resonance signal; and
- 25 b) means to add coherently the signals detected by the two or more sensors to thereby improve the signal-to-noise ratio.

Preferably, the two or more sensors are used solely for sensing, i.e., receiving, the NQR signal, and a separate coil is used as the transmit coil.

- 30 Preferably, the two or more sensors are high temperature superconductor coils. More preferably, the two or more sensors are high temperature superconductor planar coils. Most preferably, the HTS sensors are each comprised of two or more coupled high temperature
- 35 superconductor self-resonant planar coils.

This invention for improving the signal-to-noise ratio and thereby the performance of a nuclear quadrupole resonance detection system is especially

important when the nuclear quadrupole resonance detection system is used for detecting the nuclear quadrupole resonance of explosives, drugs and other contraband.

5 BRIEF DESCRIPTION OF THE DRAWING

Figure 1 shows the HTS coil design of an HTS coil used in the Example.

Figure 2 is a schematic diagram of the experimental set-up used in the Example.

10 DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The instant invention provides a method for increasing the signal-to-noise ratio of a NQR detection system for scanning a potential source of NQR and a NQR detection system that provides this increased
15 performance. To accomplish this, two or more sensors are tuned to a specified nuclear quadrupole resonance frequency and the signals detected by the two or more sensors are added coherently. As used herein, "tuned to a specified nuclear quadrupole resonance frequency"
20 means that the two or more sensors are tuned to a frequency within a given nuclear quadrupole resonance emission line so that even if the two or more sensors are not tuned to exactly the same frequency, they are still detecting the same emission line.

25 The two or more sensors to detect the nuclear quadrupole resonance can be used only as receive coils or as transmit and receive coils. Preferably, separate coils are used to transmit the RF signal and to detect any NQR signal and the sensors are used solely as
30 receive coils.

The transmit coils used in this invention can be made of copper, silver, aluminum or a high temperature superconductor. A copper, silver or aluminum coil is preferably in the form of a shielded-loop resonator
35 (SLR) coil. SLR's have been developed to eliminate the detuning effect of the electrical interaction between the coil and the surrounding material.

Preferably, a copper SLR transmit coil is used to apply the RF signal to the sample.

Preferably, the two or more sensors are high temperature superconductor (HTS) coils. A high temperature superconductor coil is preferably in the form of a self-resonant planar coil, i.e., a surface coil, with a coil configuration of HTS on one or, preferably, both sides of a substrate. High temperature superconductors are those that superconduct above 77K. The high temperature superconductors used to form the HTS self-resonant coil are preferably selected from the group consisting of $\text{YBa}_2\text{Cu}_3\text{O}_7$, $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$, $\text{TlBa}_2\text{Ca}_2\text{Cu}_3\text{O}_9$, $(\text{TlPb})\text{Sr}_2\text{CaCu}_2\text{O}_7$ and $(\text{TlPb})\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_9$. Most preferably, the high temperature superconductor is $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$. It is often advantageous to be able to fine-tune the resonance frequency of the sensor. One means for accomplishing such tuning is to use two or more coupled high temperature superconductor self-resonant coils. The resonance frequency of the fundamental symmetric mode of the two or more coupled high temperature superconductor self-resonant coils can be varied by mechanically displacing the coils with respect to one another and these coupled coils serve as the HTS sensor. Preferably, the two or more coils are planar, i.e., surface, coils. Each planar coil can have an HTS coil configuration on only one side of the substrate, but preferably, has essentially identical HTS coil configurations on both sides of the substrate. Most preferably, each HTS sensor is comprised of two or more coupled high temperature superconductor self-resonant planar coils.

A HTS self-resonant coil can be formed by various known techniques. A preferred technique is described in the Example.

As indicated above, when two or more coupled high temperature superconductor self-resonant coils are used as a sensor, the resonance frequency of the fundamental symmetric mode of the two or more coupled high

temperature self-resonant coils can be varied by mechanically displacing the coils with respect to one another and this is one means to tune the resonance frequency of the sensor to a specified nuclear quadrupole resonance frequency. Alternatively, a circuit can be used to provide the tuning of the resonance frequency of the sensor to a specified nuclear quadrupole resonance frequency. The circuit can be comprised of a single loop or coil to inductively couple the circuit to the high temperature superconductor self-resonant sensor, a reactance in series with the single loop or coil and means to enable the reactance to be connected to and disconnected from the single loop or coil. The single loop or coil can be made of a regular conductor such as copper or a high temperature superconductor. The reactance can be an inductance, capacitance or combination of both. Preferably, the means to enable the reactance to be connected to and disconnected from the single loop or coil is comprised of at least one mechanical switch or diode. Preferably, the reactance can be varied so that the resonance frequency can be adjusted to more than one frequency. One way of accomplishing a variable reactance is to have the reactance comprised of two or more capacitors in parallel, each of which can be individually connected to or disconnected from the single loop or coil. Alternatively, a variable reactance can be comprised of two or more inductors in series, each of which can be individually connected to or disconnected from the single loop or coil by a switch or diode that can short-circuit the inductor and thereby essentially remove it from the circuit.

The NQR signals detected by the two or more sensors can be added coherently, i.e., the phases of the individual signals are adjusted to add constructively, by various analog and digital techniques. In the analog technique for coherent addition, the electrical path from each sensor to the

combination point, at which the signals are added, is adjusted so that the signals add constructively at the combination point. When the two or more sensors are essentially equidistant from the sample that is the source of the nuclear quadrupole resonance signal, the electrical paths from the sensors to the combination point can be made essentially identical thereby insuring that the signals add constructively at the combination point. In the digital technique for coherent addition, before combination each signal detected by the two or more sensors is multiplied by a constant complex factor that can be measured or calculated to correct for phase differences between the signal paths and thereby insure that the signals add constructively at the combination point. The constant complex factor is specific to each electrical path from each sensor to the combination point. Typically, the signals will be amplified before they are added.

The advantages in using an array of two or more sensors over using of a single sensor can be seen as follows. The signal S obtained by using an array of n sensors and coherently adding the signals is proportional to n . Assuming that the noise present is random, the noise N , after the coherent addition, is proportional to $n^{0.5}$. Therefore S/N is proportional to $n^{0.5}$, i.e., the square root of n . An array of two sensors therefore increases S/N by a factor of 1.4. An array of four sensors increases S/N by a factor of 2.

The use of HTS self-resonant coils as sensors makes the instant invention especially attractive. The HTS self-resonant coils have high Q 's and relatively small size and make the use of an array of two or more sensors more feasible.

Provision must be made for a power supply to supply power for transmitting the RF pulse. If one or more HTS coils are used, provision must also be made for cooling the HTS to liquid nitrogen temperature.

EXAMPLE OF THE INVENTION

The purpose of this Example is to demonstrate the increase in S/N when two sensors are used to simultaneously detect a frequency and the signals from the sensors are added coherently.

Each HTS self-resonant sensor is comprised of two coupled essentially identical $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$ planar coils. Each of the coupled coils is on a lanthanum aluminate (LaAlO_3) substrate with the coil design configuration shown in Figure 1 on both sides of the substrate.

A clean, polished single crystal LaAlO_3 substrate with a diameter of 2 inches (5.1 cm) and an approximate thickness of 0.02 inches (0.5 mm) was obtained from Litton Airtron, Morris Plains, NJ. Off-axis magnetron sputtering of a Ba:Ca:Cu oxide target was used to deposit, at room temperature (about 20°C), an amorphous precursor Ba:Ca:Cu oxide film on both sides of the substrate. This amorphous Ba:Ca:Cu oxide film was about 550 nm thick and had a stoichiometry of about 2:1:2. The precursor film was then thallinated by annealing it in air for about 45 minutes at 850°C in the presence of a powder mixture of $\text{Tl}_2\text{Ba}_2\text{Ca}_2\text{Cu}_3\text{O}_{10}$ and Tl_2O_3 . When this powder mixture is heated, Tl_2O evolves from the powder mixture, diffuses to the precursor film and reacts with it to form the $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$ phase.

The sample was then coated with photoresist on both sides and baked. A coil design mask with the design shown in Figure 1 was prepared. The coil has an inner radius of about 10.5 mm and an outer radius of about 22.5 mm. The outermost HTS ring 31 of the coil is about 2 mm wide and the innermost HTS ring 32 is about 3.5 mm wide. The intermediate HTS rings 33 are about 250 μm wide with about 250 μm gaps between the rings. The coil design mask was then centered on the photoresist covering the $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$ film on the front side of the substrate and exposed to ultraviolet light. The coil design mask was then centered on the

photoresist covering the $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$ film on the back side of the substrate and exposed to ultraviolet light. The resist was then developed on both sides of the substrate and the portion of the $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$ film exposed when the resist was developed was etched away by argon beam etching. The remaining photoresist layer was then removed by an oxygen plasma. The result was a coil structure comprised of the single crystal LaAlO_3 substrate with a high temperature superconductor $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$ pattern of the configuration shown in Figure 1 centered on each side of the single crystal LaAlO_3 substrate. The process was repeated three times in essentially the same way to produce three coils essentially identical to the first.

A schematic diagram of the experimental set-up used to demonstrate the increase in S/N when two sensors are used and the signals from the sensors are added coherently is shown in Figure 2. Two of the essentially identical coils were used as one sensor 11. Sensor 11 demonstrates the use of a sensor comprised of two coupled high temperature superconductor self-resonant planar coils. The other two essentially identical coils were used as the second sensor 12. The sensors 11 and 12 were each immersed in liquid nitrogen held in Nalgene® (Nalge Nunc International, Rochester, NY) dewars 13 and 14, respectively, and each was tuned to 3.6 MHz. An Agilent E4433B Signal Generator (Agilent Technologies, Palo Alto, CA) 15 and a transmit loop 16 were used in place of a NQR source. The transmit loop 16 was comprised of a loop of copper wire approximately 2 cm in diameter. The transmit loop 16 was placed so that the sensors 11 and 12 were approximately equidistant from it, i.e., about 0.5 m away from each of the sensors, with the plane of the transmit loop parallel to the planes of the coils of the sensors. The transmit loop was formed by removing the outer jacket and dielectric spacer from a piece of 0.080 inch (2 mm) coax cable 17. The transmit loop was

formed by bending the inner conductor into a circle and soldering it to the outer jacket of the coax cable just outside the point where the jacket and dielectric were removed. The signal generator provided a -10dBm signal at a frequency of 3.6 MHz. Two pick-up coils 18 and 19, each comprised of a loop of copper wire, were placed about 1 inch (2.5 cm) away from the sensors 11 and 12, respectively, with the plane of the pick-up coils parallel to the planes of the coils of the sensors. Each of the pick-up coils 18 and 19 was formed by removing the outer jacket and dielectric spacer from a piece of 0.080 inch (2 mm) coax cable 20 and 21, respectively. The loop was formed by bending the inner conductor into a circle and soldering it to the outer jacket of the coax cable just outside the point where the jacket and dielectric were removed. The coax cables 20 and 21 were each connected to a 93 ohm 2 m piece of RG62 cable 22 and 23, respectively, which were connected to a 50 ohm tee 24. This insured that the electrical phase along the two paths was essentially the same. The output of the tee 24 was fed to a Spectrum Analyzer R&S FSP 25 (Rohde & Schwarz GmbH & Co., KG, Munchen, Germany).

The signal with only one sensor present was compared to that obtained using the two sensors. The use of the two sensors resulted in a 6 dB increase in signal. This demonstrates the increase in S/N when two sensors are used to simultaneously detect a frequency and the signals from the sensors are added coherently.

CLAIMS

What is claimed is:

1. A method for improving the performance of a
5 nuclear quadrupole resonance detection system, the improvement comprising:
 - a) using two or more sensors tuned to a specified nuclear quadrupole resonance frequency, wherein
10 said two or more sensors simultaneously receive the specified nuclear quadrupole resonance signal; and
 - b) adding coherently the signals detected by said two or more sensors to thereby improve the signal-to-noise ratio.
2. The method of claim 1, wherein said two or
15 more sensors are used solely to detect said specified nuclear quadrupole resonance signal.
3. The method of claim 1, wherein said two or
20 more sensors are high temperature superconductor self-resonant planar coils.
4. The method of claim 1, wherein said two or
more sensors are each comprised of two or more coupled high temperature superconductor self-resonant planar
coils.
5. The method of claim 3 or 4, wherein said two
25 or more sensors are used solely to detect said specified nuclear quadrupole resonance signal.
6. The method of claim 3 or 4, wherein the high
temperature superconductor is selected from the group
30 consisting of $\text{YBa}_2\text{Cu}_3\text{O}_7$, $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$, $\text{TlBa}_2\text{Ca}_2\text{Cu}_3\text{O}_9$, $(\text{TlPb})\text{Sr}_2\text{CaCu}_2\text{O}_7$, and $(\text{TlPb})\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_9$.
7. The method of claim 6, wherein said high
temperature superconductor is $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$.
8. The method of any of claims 1-4, further
35 comprising using a copper shielded-loop resonator coil to apply the RF signal to the sample to be scanned for

nuclear quadrupole resonance, thereby exciting the quadrupolar nuclei of said sample.

9. The method of any of claims 1-4, wherein the electrical path from each of said two or more sensors
5 to the combination point is adjusted so that said signals add constructively at said combination point.

10. The method of any of claims 1-4, wherein said two or more sensors are essentially equidistant from the sample that is the source of said nuclear
10 quadrupole resonance signal and the electrical paths from each of said two or more sensors to the combination point are essentially identical so that said signals add constructively at said combination point.

11. The method of any of claims 1-4, wherein before combination said signals are each multiplied by a constant complex factor specific to each electrical path from each of said two or more sensors to the combination point to correct for phase differences
20 between the signal paths and thereby insure that said signals add constructively at said combination point.

12. A nuclear quadrupole resonance detection system, comprising:

a) two or more sensors tuned to a specified
25 nuclear quadrupole resonance frequency, wherein said two or more sensors simultaneously receive the specified nuclear quadrupole resonance signal; and

b) means to add coherently the signals detected by
30 said two or more sensors to thereby improve the signal-to-noise ratio.

13. The nuclear quadrupole resonance detection system of claim 12, wherein said two or more sensors are used solely to detect said nuclear quadrupole
35 resonance signal.

14. The nuclear quadrupole resonance detection system of claim 12, wherein said two or more sensors

are high temperature superconductor self-resonant planar coils.

15 The nuclear quadrupole resonance detection system of claim 12, wherein said two or more sensors are each comprised of two or more coupled high temperature superconductor self-resonant planar coils.

16 The nuclear quadrupole resonance detection system of claim 14 or 15, wherein said two or more sensors are used solely to detect said nuclear quadrupole resonance signal.

17 The nuclear quadrupole resonance detection system of claim 14 or 15, wherein said high temperature superconductor is selected from the group consisting of $\text{YBa}_2\text{Cu}_3\text{O}_7$, $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$, $\text{TlBa}_2\text{Ca}_2\text{Cu}_3\text{O}_9$, $(\text{TlPb})\text{Sr}_2\text{CaCu}_2\text{O}_7$ and $(\text{TlPb})\text{Sr}_2\text{Ca}_2\text{Cu}_3\text{O}_9$.

18 The nuclear quadrupole resonance detection system of claim 17, wherein said high temperature superconductor is $\text{Tl}_2\text{Ba}_2\text{CaCu}_2\text{O}_8$.

19 The nuclear quadrupole resonance detection system of any of claims 12-15, further comprising a copper shielded-loop resonator coil to apply the RF signal to the sample to be scanned for nuclear quadrupole resonance, thereby exciting the quadrupolar nuclei of said sample.

20 The nuclear quadrupole resonance detection system of any of claims 12-15, further comprising electrical paths from each of said two or more sensors to a combination point at which said signals are added, wherein the electrical path from each of said two or more sensors to said combination point is adjusted so that said signals add constructively at said combination point.

21 The nuclear quadrupole resonance detection system of any of claims 12-15, further comprising electrical paths from each of said two or more sensors to a combination point at which said signals are added, wherein said two or more sensors are essentially equidistant from the sample that is the source of said

nuclear quadrupole resonance signal and said electrical paths from each of said two or more sensors to said combination point are essentially identical so that said signals add constructively at said combination point.

22.The nuclear quadrupole resonance detection system of any of claims 12-15, further comprising electrical paths from each of said two or more sensors to a combination point at which said signals are added, wherein before combination said signals are each multiplied by a constant complex factor specific to each electrical path from each of said two or more sensors to the combination point to correct for phase differences between the signal paths and thereby insure that said signals add constructively at said combination point.

23.The nuclear quadrupole resonance detection system of any of claims 12-15, wherein said nuclear quadrupole resonance detection system is used to detect explosives, drugs or other contraband.

24.The nuclear quadrupole resonance detection system of claim 16, wherein said nuclear quadrupole resonance detection system is used to detect explosives, drugs or other contraband.

25.The nuclear quadrupole resonance detection system of claim 17, wherein said nuclear quadrupole resonance detection system is used to detect explosives, drugs or other contraband.

26.The nuclear quadrupole resonance detection system of claim 18, wherein said nuclear quadrupole resonance detection system is used to detect explosives, drugs or other contraband.

27.The nuclear quadrupole resonance detection system of claim 19, wherein said nuclear quadrupole resonance detection system is used to detect explosives, drugs or other contraband.

28.The nuclear quadrupole resonance detection system of claim 20, wherein said nuclear quadrupole

resonance detection system is used to detect explosives, drugs or other contraband.

29.The nuclear quadrupole resonance detection system of claim 21, wherein said nuclear quadrupole
5 resonance detection system is used to detect explosives, drugs or other contraband.

30.The nuclear quadrupole resonance detection system of claim 22, wherein said nuclear quadrupole resonance detection system is used to detect
10 explosives, drugs or other contraband.

TITLE

THE USE OF TWO OR MORE SENSORS IN A NUCLEAR QUADRUPOLE
RESONANCE DETECTION SYSTEM TO IMPROVE SIGNAL-TO-NOISE
RATIO

5

ABSTRACT OF THE INVENTION

10 The use of two or more sensors tuned to the same
nuclear quadrupole resonance frequency and
simultaneously detecting the nuclear quadrupole
resonance signal results in improved signal-to-noise
ratio and therefore improved nuclear quadrupole
resonance detection system performance.

15

20

25

30

35

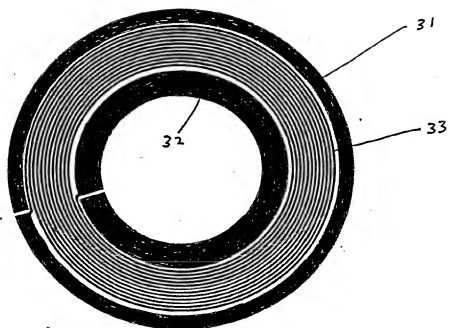


FIGURE 1

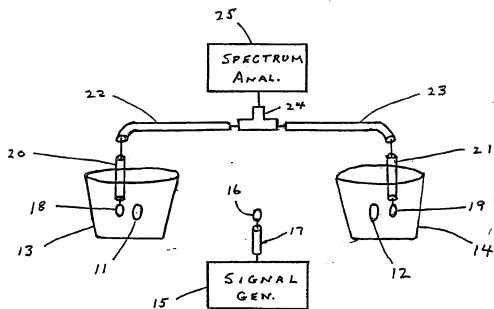


FIGURE 2